

#1. Race Condition

1. 다음 기능을 하는 프로그램을 만드시오

- 1) 데이터 파일의 마지막 숫자를 읽어서 1을 더해서 그 파일의 끝에 추가해서 기록 (데이터 파일은 초기에 0 만 써있다.)
- 2) 위 함수를 100번 호출
- 3) 이 프로그램을 실행하면 0 부터 100까지 101개의 숫자가 기록될 것이다.

2. 이 프로그램을 두개 이상 동시에 실행하여 결과를 살펴보세요

- 1) n개를 동시에 실행했을 때 파일의 마지막 숫자가 $100 \times n$ 인가?
예: 2개를 동시에 실행했을 때 200
- 2) 결과가 $100 \times n$ 이 아니라면 그 원인은 무엇인지 설명하시오.

작성한 코드(OS_HW1.c)는 argument로 스레드의 수(최대 2 개)를 입력받아, 그 수만큼의 간단한 스레드함수를 실행하는 프로그램입니다.

- 다음은 프로그램 실행예시입니다. 우선 한개의 스레드만 작동하는 조건입니다.

```

johnnyccloud:Desktop cheh344$ ./OS_HW1
Usage : ./filename <number(s) of thread(s) : 1 or 2>
johnnyccloud:Desktop cheh344$ ./OS_HW1 1
[1][Thread ID : 1] get 0, put 1
[2][Thread ID : 1] get 1, put 2
[3][Thread ID : 1] get 2, put 3
[4][Thread ID : 1] get 3, put 4
[5][Thread ID : 1] get 4, put 5
[6][Thread ID : 1] get 5, put 6
[7][Thread ID : 1] get 6, put 7
[8][Thread ID : 1] get 7, put 8
[9][Thread ID : 1] get 8, put 9
[10][Thread ID : 1] get 9, put 10
[11][Thread ID : 1] get 10, put 11
[12][Thread ID : 1] get 11, put 12
[13][Thread ID : 1] get 12, put 13
[14][Thread ID : 1] get 13, put 14
[15][Thread ID : 1] get 14, put 15
[16][Thread ID : 1] get 15, put 16
[17][Thread ID : 1] get 16, put 17
[18][Thread ID : 1] get 17, put 18
[19][Thread ID : 1] get 18, put 19
[20][Thread ID : 1] get 19, put 20
[21][Thread ID : 1] get 20, put 21
[22][Thread ID : 1] get 21, put 22
[23][Thread ID : 1] get 22, put 23
[24][Thread ID : 1] get 23, put 24
[25][Thread ID : 1] get 24, put 25
[26][Thread ID : 1] get 25, put 26
[27][Thread ID : 1] get 26, put 27
[28][Thread ID : 1] get 27, put 28
[29][Thread ID : 1] get 28, put 29
[30][Thread ID : 1] get 29, put 30
[31][Thread ID : 1] get 30, put 31
[32][Thread ID : 1] get 31, put 32
[33][Thread ID : 1] get 32, put 33
[34][Thread ID : 1] get 33, put 34
[35][Thread ID : 1] get 34, put 35
[36][Thread ID : 1] get 35, put 36
[37][Thread ID : 1] get 36, put 37
[38][Thread ID : 1] get 37, put 38
[39][Thread ID : 1] get 38, put 39
[40][Thread ID : 1] get 39, put 40
[41][Thread ID : 1] get 40, put 41
[42][Thread ID : 1] get 41, put 42
[43][Thread ID : 1] get 42, put 43
[44][Thread ID : 1] get 43, put 44
[45][Thread ID : 1] get 44, put 45
[46][Thread ID : 1] get 45, put 46
[47][Thread ID : 1] get 46, put 47
[48][Thread ID : 1] get 47, put 48
[49][Thread ID : 1] get 48, put 49
[50][Thread ID : 1] get 49, put 50
[51][Thread ID : 1] get 50, put 51
[52][Thread ID : 1] get 51, put 52
[53][Thread ID : 1] get 52, put 53
[54][Thread ID : 1] get 53, put 54
[55][Thread ID : 1] get 54, put 55
[56][Thread ID : 1] get 55, put 56
[57][Thread ID : 1] get 56, put 57
[58][Thread ID : 1] get 57, put 58
[59][Thread ID : 1] get 58, put 59
[60][Thread ID : 1] get 59, put 60
[61][Thread ID : 1] get 60, put 61
[62][Thread ID : 1] get 61, put 62
[63][Thread ID : 1] get 62, put 63
[64][Thread ID : 1] get 63, put 64
[65][Thread ID : 1] get 64, put 65
[66][Thread ID : 1] get 65, put 66
[67][Thread ID : 1] get 66, put 67
[68][Thread ID : 1] get 67, put 68
[69][Thread ID : 1] get 68, put 69
[70][Thread ID : 1] get 69, put 70
[71][Thread ID : 1] get 70, put 71
[72][Thread ID : 1] get 71, put 72
[73][Thread ID : 1] get 72, put 73
[74][Thread ID : 1] get 73, put 74
[75][Thread ID : 1] get 74, put 75
[76][Thread ID : 1] get 75, put 76
[77][Thread ID : 1] get 76, put 77
[78][Thread ID : 1] get 77, put 78
[79][Thread ID : 1] get 78, put 79
[80][Thread ID : 1] get 79, put 80
[81][Thread ID : 1] get 80, put 81
[82][Thread ID : 1] get 81, put 82
[83][Thread ID : 1] get 82, put 83
[84][Thread ID : 1] get 83, put 84
[85][Thread ID : 1] get 84, put 85
[86][Thread ID : 1] get 85, put 86
[87][Thread ID : 1] get 86, put 87
[88][Thread ID : 1] get 87, put 88
[89][Thread ID : 1] get 88, put 89
[90][Thread ID : 1] get 89, put 90
[91][Thread ID : 1] get 90, put 91
[92][Thread ID : 1] get 91, put 92
[93][Thread ID : 1] get 92, put 93
[94][Thread ID : 1] get 93, put 94
[95][Thread ID : 1] get 94, put 95
[96][Thread ID : 1] get 95, put 96
[97][Thread ID : 1] get 96, put 97
[98][Thread ID : 1] get 97, put 98
[99][Thread ID : 1] get 98, put 99
[100][Thread ID : 1] get 99, put 100
johnnyccloud:Desktop cheh344$
  
```

[기대했던 결과가 나옵니다.]

- 다음은 두개의 스레드를 작동하는 조건입니다.

```

johnnyccloud:Desktop cheh344$ ./hw1 2
[1][Thread ID : 1] get 0, put 1
[2][Thread ID : 2] get 0, put 1
[3][Thread ID : 1] get 1, put 2
[4][Thread ID : 2] get 0, put 1
[5][Thread ID : 1] get 1, put 2
[6][Thread ID : 2] get 2, put 3
[7][Thread ID : 1] get 3, put 4
[8][Thread ID : 2] get 4, put 5
[9][Thread ID : 2] get 5, put 6
[10][Thread ID : 1] get 3, put 4
[11][Thread ID : 2] get 4, put 5
[12][Thread ID : 1] get 5, put 6
[13][Thread ID : 1] get 6, put 7
[14][Thread ID : 2] get 4, put 5
[15][Thread ID : 2] get 5, put 6
[16][Thread ID : 1] get 6, put 7
[17][Thread ID : 2] get 7, put 8
[18][Thread ID : 1] get 8, put 9
[19][Thread ID : 2] get 9, put 10
[20][Thread ID : 1] get 10, put 11
[21][Thread ID : 1] get 11, put 12
[22][Thread ID : 2] get 9, put 10
[23][Thread ID : 1] get 10, put 11
[24][Thread ID : 2] get 11, put 12
[25][Thread ID : 1] get 12, put 13
[26][Thread ID : 2] get 13, put 14
[27][Thread ID : 1] get 14, put 15
[28][Thread ID : 2] get 13, put 14
[29][Thread ID : 1] get 14, put 15
[30][Thread ID : 2] get 15, put 16
[31][Thread ID : 1] get 16, put 17
[32][Thread ID : 2] get 15, put 16
[33][Thread ID : 1] get 16, put 17
[34][Thread ID : 2] get 15, put 16
[35][Thread ID : 2] get 16, put 17
[36][Thread ID : 1] get 16, put 17
[37][Thread ID : 2] get 17, put 18
[38][Thread ID : 1] get 16, put 17
[39][Thread ID : 2] get 17, put 18
[40][Thread ID : 1] get 16, put 17
[41][Thread ID : 2] get 17, put 18
[42][Thread ID : 1] get 18, put 19
[43][Thread ID : 2] get 19, put 20
[44][Thread ID : 1] get 18, put 19
[45][Thread ID : 1] get 19, put 20
[46][Thread ID : 2] get 19, put 20
[47][Thread ID : 1] get 20, put 21
[48][Thread ID : 2] get 21, put 22
[49][Thread ID : 1] get 21, put 22
[50][Thread ID : 2] get 21, put 22
[51][Thread ID : 1] get 22, put 23
[52][Thread ID : 2] get 21, put 22
[53][Thread ID : 1] get 22, put 23
[54][Thread ID : 2] get 23, put 24
[55][Thread ID : 2] get 24, put 25
[56][Thread ID : 1] get 22, put 23
[57][Thread ID : 2] get 23, put 24
[58][Thread ID : 1] get 24, put 25
[59][Thread ID : 2] get 25, put 26
[60][Thread ID : 1] get 26, put 27
[61][Thread ID : 2] get 27, put 28
[62][Thread ID : 1] get 26, put 27
[63][Thread ID : 1] get 27, put 28
[64][Thread ID : 2] get 27, put 28
[65][Thread ID : 1] get 28, put 29
[66][Thread ID : 2] get 27, put 28
[67][Thread ID : 1] get 28, put 29
[68][Thread ID : 2] get 29, put 30
[69][Thread ID : 1] get 30, put 31
[70][Thread ID : 2] get 31, put 32
[71][Thread ID : 1] get 32, put 33

[71][Thread ID : 1] get 32, put 33
[72][Thread ID : 2] get 31, put 32
[73][Thread ID : 1] get 32, put 33
[74][Thread ID : 2] get 31, put 32
[75][Thread ID : 1] get 32, put 33
[76][Thread ID : 2] get 31, put 32
[77][Thread ID : 1] get 32, put 33
[78][Thread ID : 2] get 33, put 34
[79][Thread ID : 1] get 34, put 35
[80][Thread ID : 1] get 32, put 33
[81][Thread ID : 2] get 33, put 34
[82][Thread ID : 1] get 32, put 33
[83][Thread ID : 2] get 33, put 34
[84][Thread ID : 1] get 34, put 35
[85][Thread ID : 1] get 35, put 36
[86][Thread ID : 2] get 33, put 34
[87][Thread ID : 1] get 34, put 35
[88][Thread ID : 2] get 35, put 36
[89][Thread ID : 1] get 36, put 37
[90][Thread ID : 2] get 37, put 38
[91][Thread ID : 1] get 38, put 39
[92][Thread ID : 2] get 39, put 40
[93][Thread ID : 1] get 40, put 41
[94][Thread ID : 2] get 39, put 40
[95][Thread ID : 1] get 40, put 41
[96][Thread ID : 2] get 41, put 42
[97][Thread ID : 2] get 42, put 43
[98][Thread ID : 1] get 43, put 44
[99][Thread ID : 2] get 44, put 45
[100][Thread ID : 1] get 43, put 44
[101][Thread ID : 1] get 44, put 45
[102][Thread ID : 2] get 44, put 45
[103][Thread ID : 2] get 45, put 46
[104][Thread ID : 1] get 44, put 45
[105][Thread ID : 1] get 45, put 46
[106][Thread ID : 2] get 45, put 46
[107][Thread ID : 1] get 46, put 47
[108][Thread ID : 2] get 47, put 48
[109][Thread ID : 1] get 48, put 49
[110][Thread ID : 2] get 47, put 48
[111][Thread ID : 1] get 48, put 49
[112][Thread ID : 2] get 47, put 48
[113][Thread ID : 1] get 48, put 49
[114][Thread ID : 2] get 49, put 50
[115][Thread ID : 1] get 50, put 51
[116][Thread ID : 2] get 51, put 52
[117][Thread ID : 2] get 52, put 53
[118][Thread ID : 1] get 50, put 51
[119][Thread ID : 1] get 51, put 52
[120][Thread ID : 2] get 52, put 53
[121][Thread ID : 1] get 53, put 54
[122][Thread ID : 2] get 52, put 53
[123][Thread ID : 1] get 53, put 54
[124][Thread ID : 2] get 52, put 53
[125][Thread ID : 1] get 53, put 54
[126][Thread ID : 2] get 52, put 53
[127][Thread ID : 2] get 53, put 54
[128][Thread ID : 1] get 53, put 54
[129][Thread ID : 2] get 54, put 55
[130][Thread ID : 1] get 55, put 56
[131][Thread ID : 2] get 56, put 57
[132][Thread ID : 1] get 57, put 58
[133][Thread ID : 2] get 58, put 59
[134][Thread ID : 1] get 59, put 60
[135][Thread ID : 2] get 60, put 61
[136][Thread ID : 1] get 59, put 60
[137][Thread ID : 1] get 60, put 61
[138][Thread ID : 2] get 61, put 62
[139][Thread ID : 1] get 61, put 62
[140][Thread ID : 2] get 60, put 61
[141][Thread ID : 1] get 61, put 62
[142][Thread ID : 1] get 61, put 62

[130][Thread ID : 1] get 55, put 56
[131][Thread ID : 2] get 56, put 57
[132][Thread ID : 1] get 57, put 58
[133][Thread ID : 2] get 58, put 59
[134][Thread ID : 1] get 59, put 60
[135][Thread ID : 2] get 60, put 61
[136][Thread ID : 1] get 59, put 60
[137][Thread ID : 1] get 60, put 61
[138][Thread ID : 2] get 60, put 61
[139][Thread ID : 1] get 61, put 62
[140][Thread ID : 2] get 60, put 61
[141][Thread ID : 1] get 61, put 62
[142][Thread ID : 2] get 61, put 62
[143][Thread ID : 1] get 61, put 62
[144][Thread ID : 2] get 62, put 63
[145][Thread ID : 1] get 62, put 63
[146][Thread ID : 2] get 62, put 63
[147][Thread ID : 1] get 63, put 64
[148][Thread ID : 2] get 62, put 63
[149][Thread ID : 1] get 63, put 64
[150][Thread ID : 2] get 64, put 65
[151][Thread ID : 1] get 65, put 66
[152][Thread ID : 2] get 63, put 64
[153][Thread ID : 1] get 64, put 65
[154][Thread ID : 1] get 63, put 64
[155][Thread ID : 2] get 64, put 65
[156][Thread ID : 1] get 65, put 66
[157][Thread ID : 2] get 66, put 67
[158][Thread ID : 1] get 65, put 66
[159][Thread ID : 1] get 66, put 67
[160][Thread ID : 2] get 66, put 67
[161][Thread ID : 1] get 67, put 68
[162][Thread ID : 2] get 68, put 69
[163][Thread ID : 1] get 68, put 69
[164][Thread ID : 2] get 67, put 68
[165][Thread ID : 1] get 68, put 69
[166][Thread ID : 2] get 67, put 68
[167][Thread ID : 1] get 68, put 69
[168][Thread ID : 1] get 67, put 68
[169][Thread ID : 2] get 68, put 69
[170][Thread ID : 1] get 68, put 69
[171][Thread ID : 2] get 69, put 70
[172][Thread ID : 1] get 70, put 71
[173][Thread ID : 2] get 71, put 72
[174][Thread ID : 1] get 72, put 73
[175][Thread ID : 1] get 73, put 74
[176][Thread ID : 2] get 72, put 73
[177][Thread ID : 1] get 73, put 74
[178][Thread ID : 2] get 74, put 75
[179][Thread ID : 1] get 75, put 76
[180][Thread ID : 2] get 76, put 77
[181][Thread ID : 1] get 77, put 78
[182][Thread ID : 2] get 78, put 79
[183][Thread ID : 1] get 79, put 80
[184][Thread ID : 2] get 78, put 79
[185][Thread ID : 1] get 79, put 80
[186][Thread ID : 2] get 80, put 81
[187][Thread ID : 1] get 81, put 82
[188][Thread ID : 2] get 80, put 81
[189][Thread ID : 1] get 81, put 82
[190][Thread ID : 2] get 81, put 82
[191][Thread ID : 1] get 82, put 83
[192][Thread ID : 2] get 83, put 84
[193][Thread ID : 1] get 84, put 85
[194][Thread ID : 2] get 83, put 84
[195][Thread ID : 1] get 84, put 85
[196][Thread ID : 2] get 84, put 85
[197][Thread ID : 1] get 84, put 85
[198][Thread ID : 2] get 85, put 86
[199][Thread ID : 1] get 86, put 87
[200][Thread ID : 1] get 85, put 86
johnnyccloud:Desktop cheh344$

```

[원하는대로 값이 나오지 않았습니다.]

여기서 문제는 두 가지로 요약할 수 있습니다.

- I. 출력문에 숫자의 중복이 보인다.
- II. 결국 200번을 작동하는 동안, 이에 맞춰 마지막 숫자가 올라가지 않았다.

다음은 소스코드의 일부입니다. 다음 함수가 2개의 Thread로 동작하게 됩니다.

```
void *__simpleThread__(void *data) {
    int id;
    char tmp[10];
    int memoryValue;
    int i = 0;
    id = *((int*)data);

    for (i = 0; i < 100; i++) {

        sleep(1);

        if (i < 100) fseek(sharedMemory, -3, SEEK_END);
        else if (i < 1000) fseek(sharedMemory, -4, SEEK_END);
        else errHandling("value overflow");

        fscanf(sharedMemory, "%d", &memoryValue);

        fprintf(sharedMemory, "%d\n", memoryValue+1);

        printf("[%d][Thread ID : %d] get %d, put %d \n",
               ++runTimes, id, memoryValue, memoryValue+1);
    }
    return 0;
}
```

* sleep()이 없을 시, 1번 스레드를 생성하고 나서, 2번 스레드를 생성하는 찰나의 순간에 1번 스레드가 작업을 끝내버리는 상황이 발생했습니다.

1

2

3

위 함수는 크게 세 영역으로 나눌 수 있습니다

1. 파일의 마지막 위치를 찾는다.
2. 마지막 위치의 숫자를 읽는다.
3. 마지막 숫자에 1을 더하여 다음 위치에 저장한다.

여기서 문제는 각각의 스레드가 따로 놀아, 서로를 제제하지 못해 다양한 문제가 발생하게 됩니다. 가령,

- 1번 스레드가 1번 영역을 실행.
- 동시에 2번 스레드가 1번 영역을 실행.
- 결국, 두 스레드가 같은 위치로 파일 포인터를 두게 된다.

더 나아가,

- 1번 스레드가 2번 영역을 진행한 직후, 2번 스레드가 꽤 많이 진행해 버리면, 1번 스레드는 '더는 마지막이 아닌 숫자'를 가져왔다고 볼 수 있다.
- 따라서 1번 스레드는 2번 스레드가 작성한 이후에 해당하는 '마지막 위치'에 '더는 마지막이 아닌 숫자'를 저장하게 된다.
- 또한, 1번 스레드에 의해 위 과정이 진행되면서 '마지막 위치'와 '마지막 숫자'가 바뀌었으므로, 2번 스레드 또한 위의 문제를 같이 겪게 된다.
- 이 문제가 반복되면서 결국 숫자의 최종값이 원하는 값($100 \times n$)에 결코 다다를 수 없게 된다.

The terminal window shows the output of a program with 50 threads. The threads are grouped into two sets of 25, each performing a sequence of 'get' and 'put' operations. The file `physicalMemory.txt` shows the state of shared memory, with values ranging from 0 to 10. Red annotations highlight the first 5 lines of the terminal output and the first 5 lines of the file, indicating a race condition where the second thread overwrites the first thread's value. Blue annotations highlight the 30th and 31st lines of the terminal output and the 30th and 31st lines of the file, indicating a race condition where both threads access the same memory location simultaneously.

Red Callout Box:

- * 1번 스레드가 진행하는 중, 2번 스레드가 진행하면서 파일 포인터를 다시 최초의 위치로 뒤버립니다.
- * 이때 1번 스레드는 한 번의 for loop을 진행한 후였고, 아까 2번 스레드가 지시한 파일 포인터(최초의 위치)에 있는 숫자(=0)를 읽어 옵니다.

Blue Callout Box:

- * 스레드 함수 내에선 다음 함수를 통해 숫자 출력을 진행합니다.

```
fprintf(sharedMemory, "%d\n", memoryValue+1);
```

- * 가끔은 두 스레드가 동시에 숫자 출력을 진행하여 30, 31번 라인과 같은 상황이 발생하기도 합니다.

위의 문제를 해결하기 위해선 위 세 영역을 Critical-Section 으로 두어, 한 스레드가 위 영역에 접근했을 시 다른 스레드의 접근을 대기시켜 주어야 할 것입니다.